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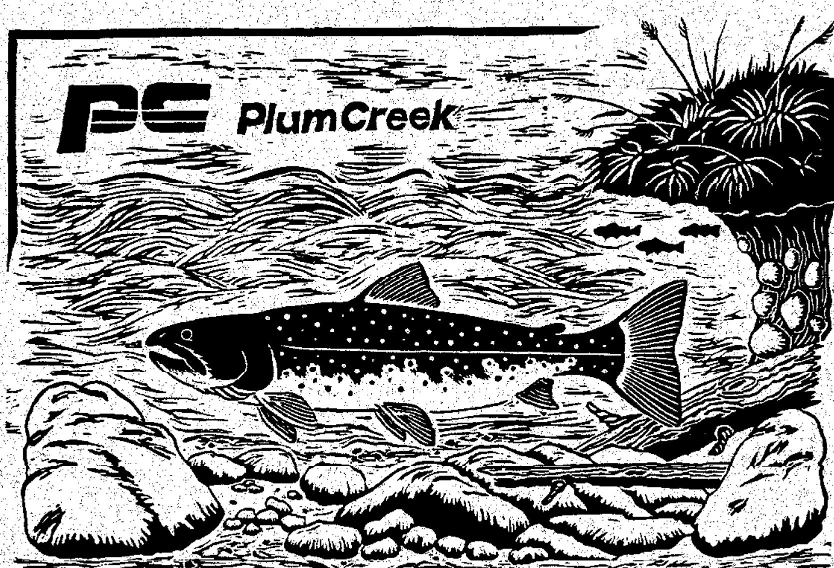
An Ecological Classification Integrating Uplands and Riverine/Riparian Habitats, Applied to the Thompson River Basin, Montana

Technical Report #4

May 20, 1998



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AN ECOLOGICAL CLASSIFICATION INTEGRATING UPLANDS AND RIVERINE/RIPARIAN HABITATS, APPLIED TO THE THOMPSON RIVER BASIN, MONTANA

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Plum Creek Aquatic Habitat Conservation Project
Technical Report #4

Plum Creek Timber Company, L.P.
Columbia Falls, Montana

1998

AN ECOLOGICAL CLASSIFICATION INTEGRATING UPLANDS AND RIVERINE/RIPARIAN HABITATS, APPLIED TO THE THOMPSON RIVER BASIN, MONTANA

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ABSTRACT

A hierarchical classification that integrates upland and riverine/riparian habitats was first developed for the upper North Fork Humboldt River in northern Nevada and later applied to other watersheds in Nevada, Oregon, California, Idaho, Washington, and Montana. The classification is a tool for assessing both the ecological potential and existing condition of riverine/riparian habitat. Habitats are viewed largely as a response to the climatic, geologic, and geomorphic processes that shaped the watershed. General levels of hierarchy used to stratify both uplands and bottom-lands are ecoregion, geologic district, and subsection. Uplands within a subsection, defined by geomorphic parameters, are further stratified at successively larger-scales into landtype associations, landtypes, habitat types, and vegetation types. Bottom-lands within a subsection are stratified as valley-bottom types, states, valley-bottom landforms, and riparian vegetation types. Valley-bottom types denote bottom-lands within a subsection with more distinctive ecological potential. States are condition classes based on channel morphology that may change in response to management. Changes in state lead to predictable changes in valley-bottom landforms and riparian vegetation types. The condition of riverine/riparian habitat can be quantified in terms of the distribution of states for a stream reach or a watershed. Results can be used to assess management, to select appropriate controls and treatments, and to extrapolate research findings to similar areas.

Key words: classification, ecological, hierarchical, geology, geomorphology, stream, riparian, state, habitat, fisheries.

INTRODUCTION

Classification is a tool for dividing objects into groups and arranging these groups into orders, such that the objects and relationships between groups can be better understood (Mill 1891). Applied to landscapes, classification can serve to identify areas with similar functional attributes that will respond to management in predictable ways. It may also help to better understand the functional character of landscapes as it applies to management.

Bailey *et al.* (1978) distinguished between an aggregating (*taxonomic)* and a subdividing (*regional*) approach to the classification of landscapes. The taxonomic approach distinguishes classes of discrete resource components such as soils (Soil Survey Staff 1975), vegetation (Daubenmire 1968; Pfister *et al.* 1977; and Hansen *et al.* 1995) or streams (Rosgen 1994; Pflieger *et al.* 1981). Typically, the criteria for distinguishing between taxonomic classes are dependent variables (*e.g.*, soil texture; plant community composition; and stream parameters such as grade and substrate). For the taxonomic approach to be comprehensive, knowledge of the variance within an entire population is required. In contrast, the *regional* approach identifies a hierarchy of successively more homogeneous areas based on independent, causative variables such as climate, geologic structure, lithology, and geomorphic history. Bailey (1995) used the regional approach to identify ecoregions of the United States and has argued (Bailey 1988) that since the interaction of energy and moisture control all biophysical processes, climate is the key to understanding ecosystems at all levels. Bailey's broadest hierarchical levels (domains and divisions), are based on climatic zones identified by Koppen (1931) and modified by Trewartha (1968), while his lower levels (province and section) are intended to be surrogate indicators of climate, namely Hammond's 1964) land surface form and Kuchler's (1964) potential natural vegetation. Bailey (1985) reviewed the environmental factors used to map ecosystems and recommended a hierarchical scheme that permits a choice of the level of detail to suit different uses.

Omernik (1995) attempted to use Bailey's map of ecoregions to stratify aquatic ecosystems on a continental scale, but was unsuccessful. The failure was attributed to Bailey's dependence on a single criterion to identify classes at each hierarchical level, which was useful in some parts of the country, but not in others. Omernik (1987) first identified ecoregions at about 1:3,000,000 scale based on key features that may change from region to region. In some areas, key features might be geologic and topographic; in others they might be soils and vegetation; in others, several features might coincide. These ecoregions have been further divided into subregions at 1:250,000 scale for some states (Gallant *et al.* 1989; Clark *et al.* 1991), again using different criteria for discriminating different subregions. In the upper Grande Ronde River basin, Bryce and Clark (1996) carried the multivariate ecoregion stratification a step further by identifying landscape level ecoregions within subregions that were intended to mesh with more thematic classifications of stream habitat proposed by Frissel *et al.* (1986), Cupp (1988), White Horse Associates (1992), Montgomery and Buffington (1993), and Rosgen (1994). Because they are constructed through the use of different data sources, these three levels do not have a specific theme (e.g. geology, geomorphology, soils, *etc.*) but are intended to distinguish areas of integrated ecosystem potential (Bryce and Clark 1996).

In contrast to the multivariate approach, Wertz and Arnold (1972) proposed the Land Systems Inventory (LSI), a hierarchical classification founded on basic, largely independent components (*e.g.*, climate, lithology, and geologic structure) that are believed to control manifest components such as soils, landform, and plant ecology. Each level of the LSI hierarchy has a specific theme and spatial scale for discriminating classes. Focused on uplands, the hierarchy ranges from physiographic provinces, typically 1000's of square *km* to landtypes and landtype phases smaller than a square *km*. The distribution of lower level components is relatively dependent on those at the next higher level. The LSI has been applied extensively to National Forest lands in the western United States and was modified to classify land capability in the Midwestern and Northeastern U.S. National Forests (Russel and Jordan 1991).

More recently, the USDA Forest Service adopted a hierarchical classification (ECOMAP 1993) that integrates domain, division, province and section (Bailey 1976) with subsection, landtype association, landtype, and landtype phase (Wertz and Arnold 1972) for conducting ecosystem management assessments. A similar classification based on climate, vegetation, and soil (including topography and parent material) is widely used in British Columbia (Pojar *et al.* 1987). Though the LSI has been extensively applied for interpreting upland land use at various scales, it does not address wetland/riparian and aquatic (stream) habitats, which are generally treated as inclusions to the upland map unit.

An international overview of regional ecological land classification was presented by Klijn and de Haes (1994). They observed that causative factors such as regional climate and geologic structure that affect the spatial dynamics of large areas tend to change very slowly, while more manifest components (*e.g.*, landform, soils, and vegetation) that affect the spatial dynamics of smaller areas change more rapidly. They conclude that this correlation between spatial and temporal scales lends merit to a classification founded on a hierarchy of predominantly abiotic processes, and suggest hierarchical levels similar to those advanced by Wertz and Arnold (1972), nested in regional levels like those of Bailey (1995) and Omernik (1987).

Many taxonomic approaches to classification of wetland/riparian ecosystems have been developed (Cowardin *et al.* 1979; Youngblood *et al.* 1985; Kovalchik 1987; Hansen *et al.* 1995; Hall and Hansen 1997) that focus primarily on the vegetative component. Harris (1988) found that the distribution of riparian vegetation in geologically and hydrologically similar watersheds of the Sierra Nevada was significantly associated with geomorphic valley types.

Many taxonomic approaches to classifying aquatic habitats have also been proposed. Attributes used to classify streams include stream age (Davis 1899), channel stability and mode of sediment transport (Schumm 1963), and morphological features such as gradient, sinuosity, width/depth ratio, substrate, channel entrenchment, confinement, and landform feature (Rosgen 1994).

Efforts to integrate the character of landscapes or watersheds with riparian/wetland and aquatic habitats have also been proposed. Lotspeich and Platts (1982) suggest an integrated land-aquatic classification system modeled after Bailey (1976), and Wertz and Arnold (1972). Benda *et al.* (1991) suggest that the distribution of stream habitats is related to geomorphology at several spatial scales. Montgomery and Buffington (1993) propose geomorphic province, watershed, valley segment, channel reach, and channel unit as levels for channel classification.

We tested a classification integrating upland and riverine/riparian habitats, as suggested by Lotspeich and Platts (1982). This approach nests levels of classification based on causative factors of the LSI (Wertz and Arnold 1972) in broader-level ecoregions (Omernik 1987; Bailey 1995) to identify landscapes with distinctive ecological potential, as suggested by Klijn and de Haes (1994). We further extended the concepts of the LSI to identify valley-bottom types with distinctive form, function, and ecological potential. Within these areas of distinctive potential, riverine/riparian habitat is further stratified as states or condition classes that correspond with distinctive hydrologic and vegetative conditions. This approach contrasts with that suggested by Bryce and Clark (1996) in that each level of classification is thematic, thus making valid comparisons and extrapolations between different areas more evident. Streams are viewed in the context of the landscape (top-down), which contrasts with the taxonomic (bottom-up) classifications typically applied to streams. Results of this classification have been used to assess range and forest management on fish and wildlife habitats.

APPROACH TO CLASSIFICATION

This approach was first developed for assessing non-point source impacts to stream and riparian habitats in the upper North Fork Humboldt River basin in northern Nevada (Jensen *et al.* 1989). It was subsequently refined by application to other basins in Nevada (White Horse Associates 1994a; 1995a; 1995b; 1997a; 1998a; 1998b), California (Platts and Jensen 1991), Washington (Chapman et al. 1994; White Horse Associates 1994b; 1996a), Oregon (White Horse Associates 1992), Idaho (White Horse Associates 1993) and Montana (White Horse Associates 1995c; 1995d; 1996b; 1997b).

A conceptual model of ecosystem components (Figure 1) served to guide the design of the classification. The model is hierarchical, meaning that for the most part lower components depend on those above. Thus, the model ranks and relates the processes that influence both the genesis and functional attributes of a landscape at successively finer spatial and temporal scales. Regional climate and geology affect large areas and change over long time-scales. Geomorphic processes affect landscapes at finer spatial and temporal scales and influence hydrologic, soil, and vegetative processes in smaller areas over shorter time-scales.

The reverse influence of lower on upper components, though sometimes less evident, are also important. Livestock may impact riparian vegetation that serves to stabilize streambanks and affect dimensions of the water column over relatively fine spatial and short temporal scales. These changes in hydrology may cause stream channel degradation, leading to alteration of geomorphic features in the valley-bottom. Long-term, cumulative effects over regions could conceivably affect geology and climate.

The goal of this classification is to group landscapes with distinctive form, function, and ecological potential and to arrange these groups into orders, such that similarities and differences between groups can be better understood. The framework consists of hierarchical levels, arranged in sequence from large to small (Figure 2). The upper levels (ecoregion, geologic district, and subsection) are founded mostly upon causative, independent variables. Subsections are divided into bottomlands, corresponding with the valley-bottom landtype, and uplands. Three levels of upland habitat (landtype association, landtype, and habitat type) are based on the successively more manifest and dependent variables of position, soil, and biotic potential. Upland vegetation types are distinguished by floristic parameters and may be seral to the habitat type.

Bottomlands correspond with the valley-bottom landtype (Figure 2), where streams and riparian habitats occur. The valley-bottom landtype within a subsection is divided into valley-bottom types that denote areas of distinctive ecological potential. Valley bottom types can be further divided into states (*i.e.*, condition classes) based on differences in channel morphology. Valley-bottom landforms and riparian vegetation types are distinguished at larger map-scales. States, valley-bottom landforms, and riparian vegetation types denote areas of distinctive condition that may change in response to common land uses.

Hierarchical levels may be thought of as layers of information, the concept on which GIS mapping is based. The top layers (*e.g.*, ecoregion) consist of large polygons that are described in terms of general criteria. At successively lower levels, polygons are divided into smaller areas according to more refined criteria, which allow increasingly specific interpretations. This classification is applied from the top-down, accounting for variability at the broadest level. The various scales used in the classification allow interpretation and generalization from broad and regional to local and specific. Information from lower levels can also support generalizations at higher levels.

In this approach, streams are not specifically classified, but stream parameters such as gradient, sinuosity, substrate, and confinement are attributes of valley-bottom type and state. This contrasts with the more taxonomic (bottom-up) approach of Rosgen (1994) who classified streams based on similar stream parameters. The range of stream parameters for valley-bottom types often straddle or span different stream types identified from the bottom-up and defined by arbitrary criteria (*e.g.* 2 to 4 percent stream grade). An advantage of the top-down approach described here is that streams can be evaluated not only in terms of parameters reflecting the existing condition or state, but also in terms of the ecological potential for the valley-bottom type.

Various sources of spatial information are used to classify landscapes. Ecoregions (Figure 2) are based on digital map files obtained from respective authors (Omernik 1987; Bailey 1995) and are used as surrogates for regional climate and broad-scale geologic structure. Geologic districts are based on the distribution of rock types from geologic maps at scales ranging from 1:500,000 to 1:43,560. Subsections are distinguished by geomorphic process evident from topographic maps and aerial photos at scales of 1:100,000 to 1:24,000. Uplands are further divided into landtype associations and landtypes denoting more discrete distributions of habitats and vegetation types.

Valley-bottom types are subdivisions of the valley-bottom landtype within a subsection, based on the geomorphic mechanism most evident in the valley-bottom, and usually occur in a predictable sequence along the valley axis. For example, the valley-bottom in an alpine glacial subsection may be divided into *glacial basin* (zone of erosion), *glacial train* (zone of transport) and *glacial outwash* (zone of deposition). The concept is similar to the *valley types* discussed by Cole

(1972), the *valley-segment types* described by Cupp (1989), the *reaches* of Gregory *et al.* (1989), the *valley segment* of Montgomery and Buffington (1993), the *geomorphic valley types* described by Harris (1988), and *reaches* discussed by Benda *et al.* (1991). The ecological potential of riverine/riparian habitat is more homogeneous within a valley-bottom type than between different valley-bottom types. Valley-bottom types can be identified from 1:24,000 scale quads and aerial photos.

Valley-bottom types with distinctive ecological potential are further divided along the valley-axis into states or condition classes, based on stream channel morphology. The concept of states was first developed through cluster and discriminate analysis of aquatic, channel and riparian attributes, measured along transects perpendicular to the stream channel (Jensen *et al.* 1989). Key parameters distinguishing states that could be determined from aerial photos were identified. In subsequent applications of the classification (Platts and Jensen 1991; White Horse Associates 1994a; 1995a; 1995b; 1995c; 1996b; 1997a; 1998a; 1998b), these key parameters were used to systematically map state boundaries from aerial photos, typically viewed at 1:2,000 to 1:6,000 scale. The channel parameters by which states are defined dictate the hydrologic variables that influence the distribution of both aquatic and riparian habitats.

A typical progression of states resulting from livestock impacts that applies to several valley-bottom types in northern Nevada is illustrated in Figure 3. The *natural state* is characterized by stable, often undercut streambanks bordered by riparian vegetation and a "fit" channel that may overflow onto the adjacent floodplain to dissipate energy. In the eroded state, active bank erosion is evident and stream channels are somewhat wider and/or more entrenched, corresponding with subtle lowering of stream and groundwater levels. This is a critical state, beyond which impacts lead to an enlarged channel, lowering of stream and groundwater levels, as illustrated for the *incised* state. The endpoint of deterioration is the *blown-out* state in which riparian vegetation has been either scoured away or left high-and-dry on stream terraces. Given rest, vegetation may stabilize the wetted channel bottom, encouraging deposition of sediments and a rise in stream and groundwater levels (*stabilized state*) that may eventually lead to the *achievable state* that is similar to the natural state, but usually at a lower base level. Harvey *et al.* (1985) describe a similar evolution of states for alluvial channels. Several other states (*e.g.*, ponded by beaver) are also common. This concept of states was integrated with a process for assessing proper functioning condition of riparian and lentic riparian-wetland areas (USDA Bureau of Land Management 1993; 1994).

In different regions (*e.g.* northern Cascades) subject to different land uses (*e.g.* forestry practices), the progression of states is usually dissimilar. In forested watersheds, changes in state may be a response to differences in sediment flux from uplands, recruitment of large woody debris, and altered flow dynamics. Streams with a large width-to-depth ratio might result from increased sediment supply, channel widening from bank trampling, or timber harvesting in the riparian zone. State must be specific to the valley-bottom type and the mechanisms of impact.

The distribution of valley-bottom landforms (*e.g.*, channel, floodplain, levee, stream terrace, alluvial fan) undergoes predictable changes in response to changes in state (Figure 3). For example, the area of the stream channel may increase at the expense of adjacent landforms and floodplains can be converted to stream terraces. Within a valley-bottom type and state, the soils and water regimes influencing biotic potential usually correlate with landform. Valley-bottom landforms in rangelands can be mapped from aerial photos viewed at 1:500 to 1:6,000 scale.

Riparian vegetation types are based on vegetative structure, species composition and water regime (Figure 4), modeled after Cowardin *et al.* (1976), and generally correlate with valley-bottom landform, state, and valley-bottom type. In the context of landform and valley-bottom type, changes in the distribution of riparian vegetation types are predictable for corresponding changes in state. For example, hydric vegetation on floodplains changes to more arid vegetation in response to channel incision and extensive, sparsely vegetated streambars often result from channel widening. Riparian vegetation types can be mapped from aerial photos viewed at 1:500 to 1:6,000 scale.

APPLICATION TO THOMPSON RIVER BASIN

The Thompson River basin (165,965 *ha*) is located in the Rocky Mountains of northwest Montana (Figure 5) and includes a stream network of 2,134 *km*. The Thompson River drains to the Clark Fork River below its confluence with the Flathead River. Average annual precipitation (USDA-SCS 1994) ranges from less than 50 *cm* in the lowest bottom-lands to greater than 150 *cm* along the highest ridges. Elevations range from 749 to 2,275 *m*.

The stream network in the Thompson River basin (Figure 5) consists of 2,299 stream reaches, counted between successive confluences. Approximately 31 percent (672 *km*) of the total stream length is perennial with an average gradient (weighted by length) of 6.5 percent (Table 1). Lower order (Strahler 1957), intermittent streams are much steeper with an average grade of 19.3 percent. The sinuosity of most streams in the Thompson River basin, defined as stream length divided by valley length, is low. Average annual yield for the Thompson River about 1 *km* upstream from the Clark Fork confluence is 39,207 *ha-m*, based on 1911 to 1994 records. About 49 percent of the basin is managed by the U.S. Forest Service, 7 percent by the State of Montana, 41 percent by Plum Creek Timber Company, and 3 percent by other private owners.

The classification, as applied to the Thompson River basin, is illustrated in Figure 6. The basin is entirely within the *northern Rockies* ecoregion (Omernik 1987), characterized as mountains with cedar/hemlock/pine, western spruce/fir, grand fir/Douglas-fir and Douglas-fir as potential natural vegetation. Major land uses include forestry and livestock grazing. Soils are described as Eastern interior mountain soils with acidic rock types, mostly Inceptisols.

Geologic district is based on the distribution of rock types digitized from 1:250,000 scale geologic maps (Harrison *et al.* 1986; 1992). The Thompson River basin and most of northwest Montana is part of the over-thrust belt, which consists of a parallel series of long ridges trending north to south, dominated by thick layers of Precambrian metasedimentary rock that have moved east along faults for distances of some tens of *km* from where they formed (Alt and Hyndman 1986). The Thompson River basin is in a *metasedimentary* geologic district, comprised or derived primarily from metamorphosed sedimentary rocks. Lower positions are filled with secondary glacial, lacustrine, and alluvial deposits.

The Thompson River basin was profoundly influenced by three geomorphic events. First, the Cordilleran ice sheet moved into northwest Montana many times during the Pleistocene (15,000 to 2.5 million years ago), scouring lower elevations and leaving thick deposits of debris. A lobe of this same ice sheet also dammed the Clark Fork River near the present Pend Oreille Lake to form glacial Lake Missoula, which at its maximum was about 610 *m* deep, covered about 8,547 square *km* and filled ice-free valleys to a maximum elevation of 1,280 *m* (Johns 1970). The lake drained 35 to 40 times in catastrophic floods when its ice dam failed. At their maximum, the Cordilleran ice sheet and glacial Lake Missoula are estimated to have covered about 39 percent of the Thompson River basin. Second, alpine glaciers scoured high mountains along the east and west flanks of the basin resulting in steep, U-shaped valleys. Third, areas above that influenced by continental glaciation and Lake Missoula, but below that affected by alpine glaciation were carved by fluvial processes, resulting in V-shaped canyons. These geomorphic events form the basis for subsections and caused the more manifest parameters evident at lower levels of the hierarchy.

Preliminary subsections and landtype associations of the Thompson River basin were identified from topographic maps and images generated from Digital Elevation Models (DEMs). Boundaries were refined through correlation with landtypes identified by the Lolo National Forest (Sasich and Lamotte-Hagen 1989) and Kootenai National Forest (Kuennen and Nielson-Geghardt 1995), and soil map units identified by the Natural Resource Conservation Service (USDA NRCS 1995; 1997).

The four subsections identified in the Thompson River basin (Figure 7) correspond with the previously described major geomorphic events. The areas scoured by continental glaciation are *metasedimentary continental glaciated erosional lands* with mostly residual soils and isolated areas of shallow glacial deposits, while areas mantled by thick deposits of continental glacial debris are *metasedimentary continental glaciated depositional lands*. The high mountains in the southern half of the basin are *metasedimentary alpine glaciated lands* with thin residual soils on scoured positions and debris left in the wake of retreating alpine glaciers along the valley-bottoms. Areas not over-ridden by alpine or continental glaciation, but shaped by stream processes are *metasedimentary fluvial lands,* with mostly residual soils.

Subsections of the Thompson River basin were further divided into component landtype associations (Figure 8 and Table 2). Landtypes and soils were correlated with landtype associations and subsections, though with discretion. Within some landtype associations and subsections, there are inclusions of landtypes and soils that occur more frequently in other classes. The regional, top-down approach provides the necessary context for judging the importance of such inclusions and for taking full advantage of landtype mapping.

The *valley-bottom landtype* was delineated by two processes. Where the valley-bottom is broad or irregular in width, it was digitized from 1:24,000 scale quads. Where it is narrow and regular, it was estimated using "buffers" on stream courses from Cartographic Feature Files (CFFs). The widths of buffers were estimated from 1:24,000 scale USGS quads, 1:40,000 scale aerial photos and 1:12,000 scale aerial photos for combinations of stream order and valley-bottom type. The total buffer width for most valley-bottom types ranges from 30 *m* for order 1, to 60 *m* for order 5, in 7.5 meter increments. For very steep and narrow valley-bottom types the buffers used are 18 *m* for order 1 and 2 streams.

The *valley-bottom landtype* (Figure 9) is 29,589 hectares (18 percent) of the Thompson River basin and includes lands shaped by contemporary stream channels, floodplains, stream terraces, and alluvial fans. Also included in the valley-bottom landtype are: 1) relatively flat surfaces of glacio-lacustrine terraces, even though these may be 120 *m* above present floodplains, and 2) steep canyon slopes along streams that have cut through these high terraces.

The morphology of the valley-bottom landtype varies between subsections. The valley-bottom in *metasedimentary alpine glaciated lands* is typically U-shaped, while that in *metasedimentary fluvial lands* is V-shaped. The depth of glacial debris and resultant shape of the valley-bottom also varies between *metasedimentary continental glaciated erosional lands* and *metasedimentary continental glaciated depositional lands*. The mode and relative effectiveness of the dominant geomorphic process identified for subsections are used to distinguish thirteen valley-bottom types in the Thompson River basin (Table 3). Stream attributes for valley-bottom types are estimated from 1:24,000 scale CFFs and DEMs.

In *alpine glaciated lands* (Figure 7), three dominant valley-bottom types occur. *Glacial basins* are broad, scoured bowls drained mostly by low order, intermittent and perennial streams, with bedrock, boulder, and cobble substrate. *Glacial trains* are broad, U-shaped canyons drained mostly by perennial streams with cobble and boulder substrate. *Glacial outwash* valley-bottoms are broad, undulating, porous surfaces of low relief, associated with streams having high bedloss.

In *fluvial lands* four dominant valley-bottom types occur. *Fluvial cascades* are low order, very steep, intermittent drainages with bedrock, boulder, and cobble substrate, which are not associated with well-developed canyons. *Fluvial basins* are very steep, low order, mostly intermittent drainages with boulder, and cobble substrate that are confined in headwater canyons. *Fluvial V-erosional canyons* are higher order, steep, mostly-perennial drainages with bedrock, boulder, and cobble substrates, and narrow, often discontinuous floodplains confined by residual slopes. *Fluvial V-depositional canyons* are drained by higher-order, mostly perennial streams of lesser gradient, with cobble and gravel substrates, flanked by broad floodplains and/or stream terraces. In *continental glaciated erosional lands,* the *fluvial basins, V-erosional canyons,* and *V-depositional canyons* are similar to those described for fluvial lands, but have lower corresponding gradients.

In *continental glaciated depositional lands* are *glacio-lacustrine basins, unconfined* which have broad, low terraces and wide, continuous floodplains along mostly perennial streams. *Glacio-lacustrine basins, confined* are incised in adjacent terraces, with narrow, sometimes discontinuous floodplains associated with intermittent and perennial streams that tend to lose water through percolation. In *glacio-lacustrine canyons,* streams have cut through most of the glacio-lacustrine deposits, resulting in a morphology similar to that of *fluvial V-depositional canyons* with continuous floodplains, but with canyon slopes of unconsolidated glacio-lacustrine sediments.

States and valley-bottom landforms were not mapped in the Thompson River basin. Dense forest canopies often obscure the view of landforms and stream channels on small-scale aerial photos. Observations in the Thompson River basin and other forested watersheds in the northwest (White Horse Associates 1994b; 1995d; 1996a) indicate that sediment entrainment, recruitment of large woody debris and flow alteration, in addition to direct impacts to the channel, are important mechanisms influencing states. States in these environs bear little resemblance to those typical of arid rangelands as shown in Figure 3.

Riparian vegetation types integrate the effects of the geomorphic processes used to define subsections and valley-bottom types with present hydrologic conditions. They are based on physiognomy and water regime identified from 1:24,000 scale orthophotos, 1:12,000 and 1:40,000 scale aerial photos, and limited ground reconnaissance. Thus, herbaceous types are saturated and semi-permanently flooded *wet meadow*, seasonally flooded *mesic meadow*, and *irrigated pasture.* Shrub types are seasonally flooded *riparian shrub* and semipermanently flooded *riparian shrub/wet meadow* with a more hydric understory. Forested types are *mixed conifer* on drier positions transitional to upland and *mixed conifer/riparian shrub* with two vegetative components bordering stream channels. The distribution of riparian vegetation types for valley-bottom types are listed in Table 4 and illustrated for part of Thompson River basin in Figure 10.

DISCUSSION

In this section we discuss results of the ecological classification for the Thompson River basin and compare the results with other applications in the western United States (Figure 11). In northern Nevada, Oregon, and California, the classification was used to assess impacts of livestock on stream and riparian resources. Classifications conducted in the upper Clark Fork River basin in west central Montana and the Panther Creek basin in northern Idaho were used to assess impacts of mining on aquatic resources for Natural Resource Damage Assessments. Application to the upper Blackfoot River basin in west central Montana is being used to evaluate potential impacts of proposed mining activities. Studies in the Thompson and Swan River basins in Montana and

Harvey/LeClerc and the Cascade basins in Washington are being used to evaluate forest management and to facilitate watershed analysis.

The diversity within ecoregions and the scale at which diversity becomes apparent are not consistent: some ecoregions are relatively similar throughout, while others encompass great variation. The range in elevation and topographic diversity may be relative measures of the diversity within an ecoregion. In the *northern Rockies* ecoregion, characterized by high mountains, the diversity corresponds with differences in geologic structure, lithology and/or geomorphic character that are apparent on relatively large-scale (*e.g.*, 1:100,000) maps. But in the *high desert/Snake River plain* ecoregion, composed of flat layers of volcanic rock, the variance occurs over large areas and can be shown on small-scale (*e.g.*, 1:500,000) maps. Consequently, more inclusive analyses at larger scales are necessary to develop a quantitative understanding of the variance within and between ecoregions (Omernik 1987). Ecoregions provide a general framework for nesting of subsequent levels of the ecological classification.

The Thompson River basin is entirely within the *northern Rockies* ecoregion (Omernik 1987) and is fundamentally similar to the Swan River basin, Harvey/LeClerc basins, Panther/Big/Loon basins, parts of the upper Blackfoot River basin, and parts of the Clark Fork/Big Hole basins (Figure 11), which are in the same ecoregion. While these basins are fundamentally similar, differences in lithology and/or differences in geomorphic character may be apparent from a closer perspective. Areas with similar lithology and geomorphology, but in different ecoregions, may be more similar than areas of different lithology and geomorphology in the same ecoregion. For example, the landforms, riparian community types, and functional attributes of *granitic alpine glaciated lands* of the Ruby Mountains in the *northern basin and range* ecoregion are more similar to *granitic alpine glaciated lands* described in the *northern Rockies* of central Idaho (Tuhy and Jensen 1982) than those typical of the surrounding ecoregion. Identification of subregions and landscape level ecoregions based on multivariate criteria which seem best suited to distinguish local landscapes, as suggested by Bryce and Clark (1996), makes such comparisons less obvious.

Geologic districts are areas of distinctive lithology or parent material. Given the fundamental influence of parent material on landform and soil, geologic districts often correspond with distinctive hydrologic character and assemblages of upland potential plant communities. Lithology is also expected to influence stream substrate, valley form, and potential water quality. Geologic districts are typically 10's to many 100's of square *km* in size. They include both uplands and bottom-lands, do not change in response to cultural practices, and denote areas of distinctive ecological potential within ecoregions.

The Thompson River basin lies within a single, *metasedimentary* geologic district, which also encompasses the Swan River basin, parts of Harvey/LeClerc basins, parts of the upper Blackfoot basin and parts of the Clark Fork/Big Hole basins within the overthrust belt. Comparison of metasedimentary landscapes in Thompson River basin with metasedimentary landscapes in the Swan River basin may be appropriate, whereas comparison with granitic landscapes in parts of the Harvey/LeClerc basins are not. In contrast to the very large *metasedimentary* geologic district in the *northern Rockies* ecoregion, much smaller districts that correspond with distinctive topography and stream variables were identified in the *northern basin and range* ecoregion of northern Nevada. The surficial geologic maps from which districts are derived may also be useful for other assessments, such as slope stability and potential habitat for endemic plant species. The boundaries of geologic districts can be refined by the analysis of topographic features viewed at larger scales, as described for subsections.

Digital geologic maps compiled at 1:500,000 scale are available from USGS for most of the western United States. When applied to small areas at larger map-scales (*e.g.*, 1:24,000), the accuracy of these maps must be evaluated. Digital geologic maps prepared by USGS at 1:250,000 and 1:100,000 scale are becoming more common, but are still not available for most areas, however, these larger-scale maps can be scanned or digitized.

Subsections, landtype associations, and landtypes are differentiated by geomorphic characteristics viewed at successively higher resolutions. Alpine glaciers, streams, the Cordilleran ice sheet, and glacial Lake Missoula had profound effects on the geomorphic character of the Thompson River basin and are principally determinate of the four subsections identified. Within subsections, specific landtype associations based on form and position are discerned from a closer (larger-scale) geomorphic perspective. Component landtypes of landtype associations are based on the refined landform and soil attributes associated with habitats. These geomorphic classes denote uplands with successively more homogenous ecological potential. Landtypes can be further divided into types based on existing vegetation and/or forest structure parameters. Thus, subsections, landtype associations, and landtypes may be useful for identifying uplands of distinctive potential that will respond similarly to disturbance.

Although subsection, landtype association, and landtype are all levels of the LSI (Wertz and Arnold. 1972), only landtypes have been identified for most of the National Forest lands in the western United States. Nesser *et al.* (1997) identified only two subsections in Thompson River basin in a first approximation of subsections for Montana, northern Idaho and North Dakota intended for use at 1:500,000 scale or smaller. Landtype associations identified for the Columbia River basin as part of a regional assessment (Quigley and Arbelbide 1997) were evaluated for use in the Thompson River basin, but were too broadly defined and did not correspond well with subsection boundaries. Landtype associations derived through the indiscriminate combination of landtypes over very large areas may be useful for regional assessments, but were found to be of limited value for specific applications in the Thompson River basin. Soil maps prepared by the Natural Resource Conservation Service (NRCS) may serve as surrogate landtypes for private and Bureau of Land Management (BLM) lands. Where landtype-level information is available, it may be compiled from the bottom-up to generate landtype associations and subsections, though not without evaluating the topographic diversity within more broadly-defined subsections. Alternatively, where studies focus on riverine/riparian habitat, landtype association and landtype mapping may not be necessary, and subsections can be delineated from topographic maps and aerial photos.

Neither landtype associations or landtypes are particularly useful for classifying streams and associated wetland/riparian habitat. Generally, the valley-bottom is treated as an inclusion to both landtype associations and landtypes. It is common to find different landtype associations and/or landtypes on opposite slopes of the same reach of valley-bottom. Subsections were found to be most useful for dividing the valley-bottom landtype into reaches, each distinguished by a dominant geomorphic process. Landtype associations and landtypes adjacent to the valley-bottom may be useful for specific interpretations, such as predicting the potential for mass wasting or surface erosion.

The valley-bottom landtype, valley-bottom type, state, valley-bottom landform, and riparian vegetation type levels are designed to focus on streams and riparian resources. Simply, the valley-bottom landtype distinguishes the relatively flat depositional surfaces near streams from residual surfaces (*e.g.*, mountain slopes). The valley-bottom landtype within a subsection may be further divided into associated valley-bottom types, each reflecting a dominant geomorphic mechanism and discrete functional attributes.

The hydrology layer of 1:24,000 scale Digital Line Graphs (DLGs) and CFFs, and 1:24,000 scale DEMs are useful both for delineating the valley-bottom landtype and for determining stream attributes within valley-bottom types. The hydrology layer includes stream courses and water bodies marked on 7.5 minute quads (US Geological Survey 1990a). The DEM is a matrix of 30x30 meter pixels spatially ordered in a standard coordinate system (*e.g.*,Universal Transverse Mercator) with an elevation assigned to each pixel (U.S. Geological Survey 1990b). Where valley-bottoms are narrow and of relatively consistent width, they can be generated as buffers centered on the digital stream course. Digital elevation models can be used to determine the upper and lower elevations of stream reaches and to estimate gradient. These measures are comparable to what can be estimated from 7.5 minute quads where the valley-bottom is wider than 60 *m*, but may be less accurate where the valley-bottom is narrow, since some DEM pixels overlap adjacent slopes. Stream sinuosity, adjusted for bends in the valley-bottom, can also be estimated from the DLGs with at least the same accuracy and with far greater efficiency than from 7.5 minute quads. Similar 1:100,000 scale DLGs and 1:250,000 scale DEMs can be used for similar purposes, but with less accuracy.

In studies of rangelands in northern Nevada, Oregon and California, and the Clark Fork/Big Hole/Ruby basins and the upper Blackfoot River basin in Montana (Figure 11), valley-bottom types were further divided along their length into states (*i.e.*, condition classes) based on channel morphology. Mapping of states requires relatively large-scale aerial photos and field validation. In northern Nevada, states were characterized using detailed measurements of aquatic and channel parameters measured in General Aquatic Wildlife Survey (GAWS) stations (USDA Forest Service 1985). In Montana (White Horse Associates 1995c; 1996b) states were characterized from results of aquatic and fisheries surveys. In the Pacific Northwest, dense forest canopies pose a challenge for delineating states of small streams from aerial photos.

States must be specific to the valley-bottom type and the mechanisms of impact. While similar progressions of states are identified for different valley-bottom types impacted by livestock grazing in the northern Great Basin, the susceptibility to impact and rates of recovery are often different. Streams in landscapes dominated by soft parent materials (*e.g.*, tuff) that weather rapidly to fine sediments tend to be more susceptible to impact and recover faster than streams in landscapes dominated by hard parent materials (*e.g.*, metasedimentary) that weather slowly to coarse sediment. States resulting from livestock impacts in the Great Basin are dissimilar to states resulting from forestry impacts in the Pacific Northwest. Assessment of riverine/riparian habitat can be quantified in terms of the distribution of states for a stream reach or a watershed.

Valley-bottom landforms were mapped for rangeland project areas in northern Nevada and Oregon (Figure 11). Changes in the distribution of landforms for corresponding changes in state were relatively predictable and usually correlated with changes in hydrology and flora. For example, channel incision corresponded with a lowering of stream and alluvial groundwater levels and conversion of floodplains to stream terraces, leaving riparian vegetation high-and-dry. Widening of the stream channel comes at the expense of other streamside landforms. It is important to consider the distribution of landforms when assessing streams. For example, where alluvial fans abut the channel, streambanks are inherently less stable than where floodplains border the stream. In forested valley-bottoms, landforms may correspond with subtle differences in overstory species composition that is difficult to detect from aerial photos, though differences in understory habitats may be evident from the ground.

The distribution of riparian vegetation types varies as a function of general landscape characteristics inherent to valley-bottom types, variables denoting state, and geomorphic/hydrologic parameters specific to each valley-bottom landform. The species composition of riparian vegetation types is more broadly defined than the community and habitat types resulting from rigorous taxonomic classifications such as those of Hall and Hansen (1977), Hansen *et al.* (1995), and Youngblood *et al.* (1985), which are usually named by a single dominant species in forest, shrub, and herbaceous strata. In contrast, the willow over-stories of riparian vegetation types in the northern Great Basin tend to be an assemblage of several co-dominant species with broadly overlapping site requirements. Understory vegetation tends to correlate with water regime (Figure 4) better than overstory vegetation. In studies in northern Nevada and Oregon (Figure 11), the distribution of riparian vegetation types correlate with landform and states of valley-bottom types.

In the Thompson River basin, results of this classification are being used to group upland and riverine/riparian habitats, to assess the similarity of watersheds, to screen for landscape hazards, and as a foundation for more intensive watershed analysis. Coupled with more intensive watershed analysis, mass wasting and surface erosion hazards have been assigned to landtypes and landtype associations. Multivariate statistical methods are used to develop groupings, or guilds, that contain similar upland vegetative communities. Stream guilds, intended to be distinctive assemblages of fish habitat with unique sensitivities to management, are being identified by valley-bottom type, stream order (Strahler 1957), and stream gradient. Results of watershed similarity analysis are being used to identify representative subbasins for more intensive analysis of the effects of forest practices on fisheries and water quality.

An important requisite of any classification system is a statement defining the limits of application (Pfister 1977). The described classification is most useful for application to the young landscapes that are common in the western United States. While some levels of hierarchy may be useful in the more weathered and subdued eastern United States, other levels will not. In dense coniferous forests, the delineation of states and landforms may not be feasible from aerial photos.

The utility of this classification is largely dependent on the selection of appropriate map units and the accuracy of mapping at different scales. More accurate mapping at larger-scales can be used to refine maps at smaller-scales. This approach to classification provides a scientific basis for stratifying landscapes into successively smaller, more homogeneous units with increasingly explicit responses to management.

ACKNOWLEDGMENTS

Support for the development and application of the classification was provided by: US Forest Service Forest Intermountain Research Station, Boise, ID; Nevada Department of Wildlife, Elko; Independence Mining Company, Elko, NV; Lassen National Forest, Susanville, CA; Montana Natural Resource Damage Assessment Program, Helena; John Day Ranger District, Ukiah, OR; US Forest Service Mountain City Ranger District, NV; Rocky Mountain Elk Foundation; Idaho State Natural Resource Damage Assessment Program, Boise; Plum Creek Timber Company L.P., Seattle, WA; Barrick Gold Mining Company, Elko, NV; Phelps Dodge Mining Company Seven-Up/Pete Joint Venture, Lincoln, MT; Bureau of Land Management, Elko District, NV; Northeastern Nevada Chapter of Trout Unlimited, Elko; US Forest Service, Santa Rosa Ranger District, Winnemucca, NV; and the Winnemucca District BLM, NV. Dr. William S. Platts provided a guiding light through early stages of development. Plum Creek Timber Company funded the publication. Dr. Phil Larsen (EPA Corvallis Research Laboratory, OR), Dr. Tracy Hillman (EcoAnalysis, Boise, ID), Dr. Mark Jensen (US Forest Service Research Branch, Forest and Range Experiment Station, Missoula, MT), Dr. Matt O'Connor (O'Connor Environmental, Inc., Healdsburg, CA) and members of the Plum Creek science staff reviewed and suggested revisions to the draft paper. C.L. Rawlins was the technical editor.

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Table 1. Stream attributes, Thompson River basin.

Stream Order	Perennial			Intermittent			Total		
	Length *(km)*	Grade (%)	Sinuosity Ratio	Length *(km)*	Grade (%)	Sinuosity Ratio	Length *(km)*	Grade (%)	Sinuosity Ratio
1	89.8	13.0	1.05	1249.2	21.0	1.05	1339.0	20.4	1.05
2	205.6	9.5	1.04	192.2	10.3	1.05	397.9	9.9	1.05
3	169.1	4.9	1.05	20.8	4.2	1.06	189.9	4.8	1.05
4	84.8	3.3	1.07	0.0	NA	NA	84.8	3.3	1.07
5	83.4	0.9	1.17	0.0	NA	NA	83.4	0.9	1.17
6	39.2	0.8	1.04	0.0	NA	NA	39.2	0.8	1.04
TOTAL	**671.9**	**6.5**	**1.06**	**1462.3**	**19.3**	**1.05**	**2134.2**	**15.3**	**1.05**

Table 2. Attributes of subsections and dominant landtype associations, Thompson River basin.

Subsection Landtype Association	Area *(ha)*	Elevation *(m)*		Slope (%)		Precipitation *(cm)*		Drainage Density *(km/square km)*	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Perennial	Total
Alpine glaciated lands	25546	1638	222	16.9	9.6	93	23	0.8	2.4
Cirque and rocky ridge	4772	1906	137	23.8	10.0	110	22	0.0	0.4
Glacial basin	1954	1798	108	15.7	8.9	125	19	1.0	3.2
Glacial trough	13548	1608	171	17.3	8.6	88	18	0.4	2.2
Moraine	4469	1367	137	9.8	7.2	80	19	2.3	4.7
Fluvial lands	83904	1472	251	19.7	8.2	78	12	0.5	1.9
Ridge	14415	1717	214	14.1	6.4	82	12	0.0	0.1
Mountain slope	53921	1467	208	19.4	7.1	78	12	0.3	2.1
Breakland	12976	1279	190	27.7	8.1	77	10	0.9	2.4
Continental glaciated erosional lands	34574	1228	125	13.6	7.1	69	8	0.3	1.7
Continental glacial ridge and slope	33090	1228	127	13.9	7.0	69	8	0.2	1.6
Continental glaciated depositional lands	21942	1064	90	4.8	5.3	65	8	1.5	2.7
High terrace	18491	1064	92	5.4	5.6	66	8	0.8	2.0
Floodplain and alluvium	2036	1035	142	7.2	7.7	68	10	10.4	12.1
Water	1164	na	na	na	na	68	14	na	na

Table 3. Attributes of valley-bottom types, Thompson River basin.

Subsection / Valley-bottom Type	Area (ha)	Width (m)	Stream Length (km)		Perennial Grade (%)		Sinuosity	
			Perennial	Intermittent	Mean	Std. Dev.	Mean	Std. Dev.
Alpine glaciated lands								
Alpine glacial basin	709	42	49.7	119.7	15.9	7.7	1.04	0.03
Alpline glacial train	357	117	30.3	0.2	7.6	5.2	1.04	0.03
Alpine glacial outwash	2406	250	45.6	50.7	3.2	2.7	1.04	0.03
Fluvial lands								
Fluvial cascade	759	19	15.5	388.3	25.1	11.9	1.04	0.03
Fluvial basin	1625	32	82.1	424.4	13.7	6.4	1.03	0.02
Fluvial V-erosional canyon	691	41	129.2	38.3	6.9	4.7	1.03	0.03
Fluvial V-depositional canyon	748	106	63.6	7.2	2.0	2.6	1.04	0.05
Continental glaciated erosional lands								
Continental fluvial basin	779	30	11.7	245.7	6.4	2.6	1.04	0.02
Continental V-erosional canyon	141	38	28.5	8.7	5.0	3.1	1.02	0.02
Continental V-depositional canyon	394	204	16.1	3.2	1.7	2.4	1.08	0.07
Continental glaciated depositional lands								
Glacio-lacustrine basin (unconfined)	3011	560	39.9	13.8	1.1	1.9	1.18	0.16
Glacio-lacustrine basin (confined)	17035	668	99.9	155.0	3.4	2.1	1.06	0.08
Glacio-lacustrine canyon	915	147	60.0	2.4	0.9	1.6	1.16	0.16

Table 4. Distributions of riparian vegetation types for valley-bottom types, Thompson River basin.

Subsection Valley-bottom type	Area *(ha)*	Riparian Vegetation Types (% Area)							
		WM	MM	IP	RS	RS/WM	MC/RS	MC	W
Alpine Glacial lands									
Alpine glacial basin	709.5	0.3	0.0	0.0	0.0	0.0	85.3	6.5	7.9
Alpine glacial train	357.4	0.0	0.0	0.0	0.0	0.0	91.2	8.8	0.0
Alpine glacial outwash	2406.5	2.6	0.5	0.0	3.8	0.8	57.0	34.5	0.8
Fluvial lands									
Fluvial cascade	759.0	0.0	0.0	0.0	0.0	0.0	99.7	0.0	0.3
Fluvial basin	1624.8	0.0	0.2	0.0	0.5	0.0	99.4	0.0	0.0
Fluvial V-erosional canyon	691.1	0.0	0.0	0.0	1.2	0.0	98.8	0.0	0.0
Fluvial V-depositional canyon	748.3	0.1	0.4	0.0	9.6	0.0	58.6	31.4	0.0
Continental glaciated erosional lands									
Continental fluvial basin	779.5	0.0	0.1	0.0	0.0	0.0	99.8	0.0	0.1
Continental V-erosional canyon	141.3	0.0	0.2	0.0	5.6	0.0	94.2	0.0	0.0
Continental V-depositional canyon	393.9	0.9	4.3	0.0	19.9	0.0	41.2	33.7	0.0
Continental glaciated depositional lands									
Glacio-lacustrine basin (unconfined)	3010.4	3.4	0.3	22.0	0.6	3.6	21.8	8.6	39.7
Glacio-lacustrine basin (confined)	17035.6	0.4	0.4	0.4	0.2	0.0	5.8	92.6	0.1
Glacio-lacustrine canyon	915.5	0.4	0.0	6.8	20.7	0.0	72.2	0.0	0.0
ALL TOTAL	**29572.6**	**0.8**	**0.4**	**2.6**	**1.7**	**0.5**	**31.0**	**58.5**	**4.4**

WM = wet meadow; MM = mesic meadow; IP = irrigated pasture; RS = riparian shrub; RS/WM = riparian shrub/wet meadow; MC/RS = mixed conifer/riparian shrub; MC = mixed conifer; W = water;

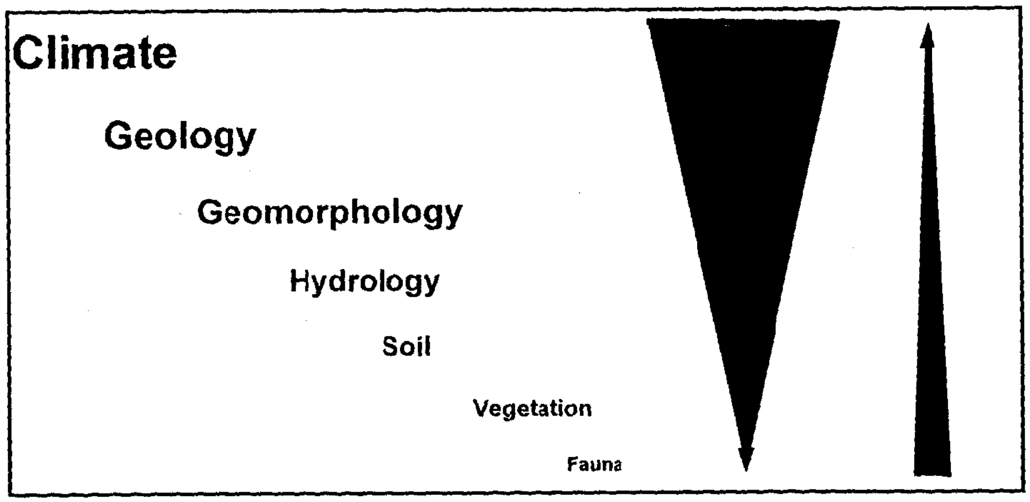

Figure 1. Hierarchical model of an ecosystem (modified from Klijn and de Haes 1994).

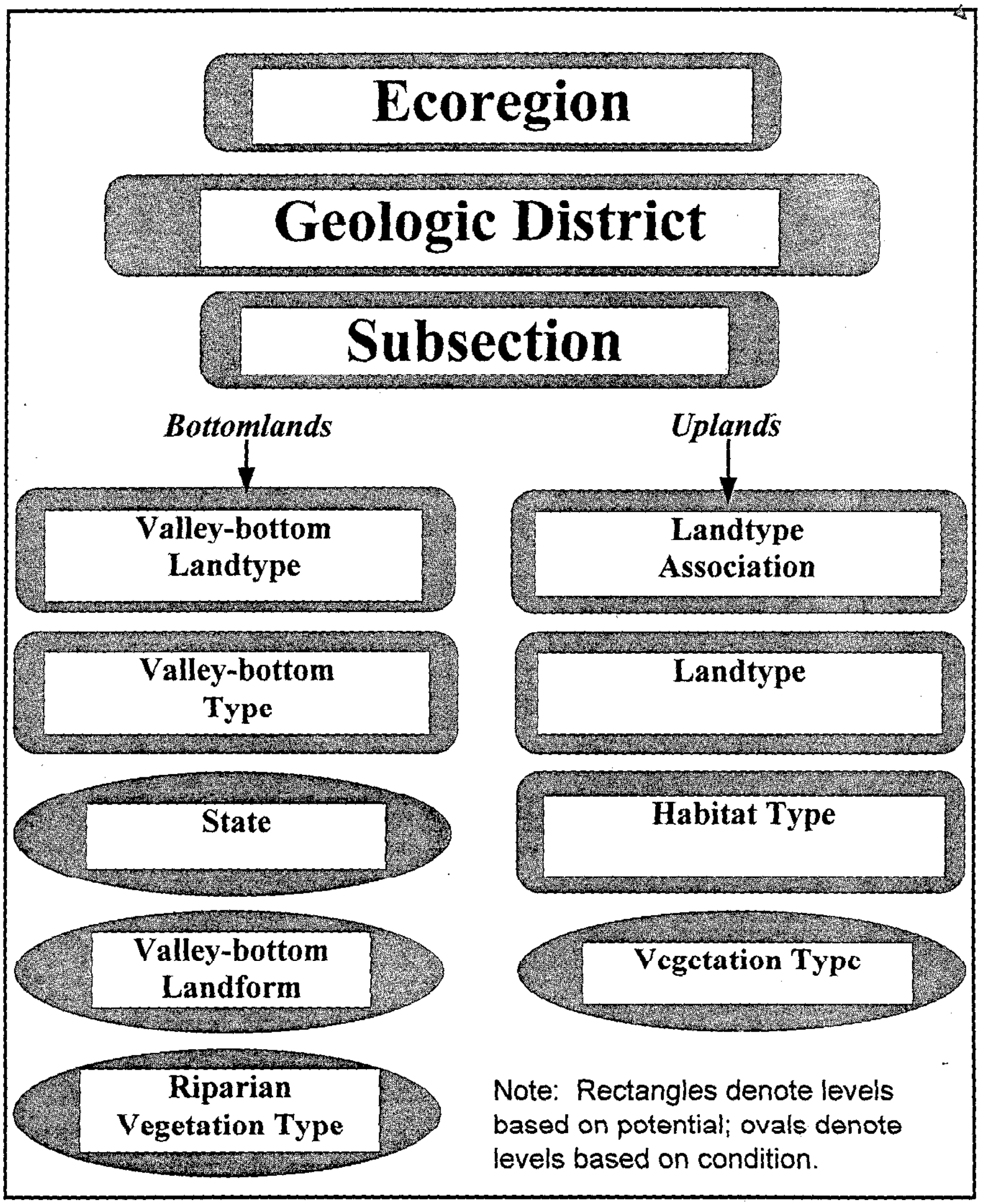

Figure 2. Classification hierarchy.

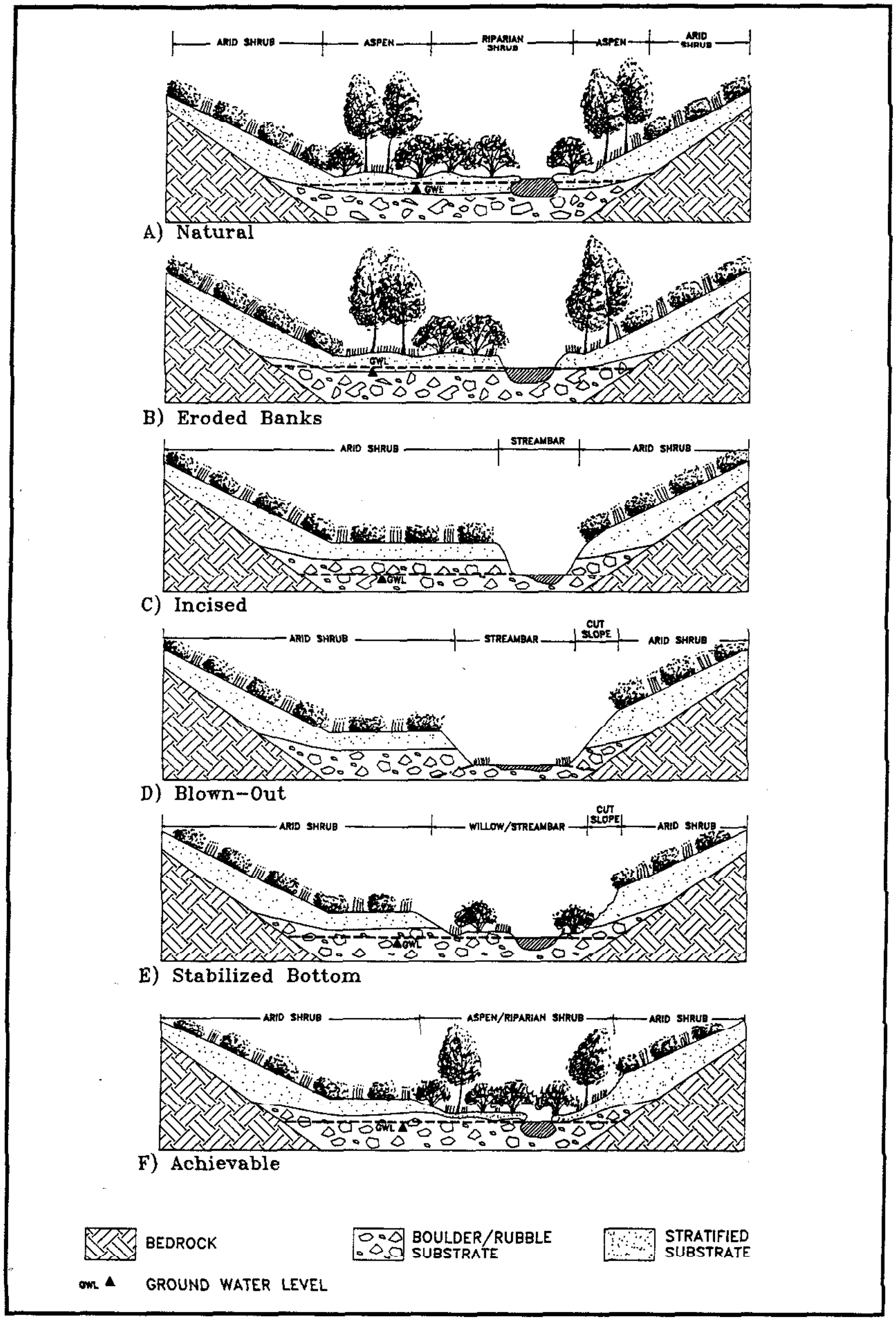

Figure 3. Progression of states.

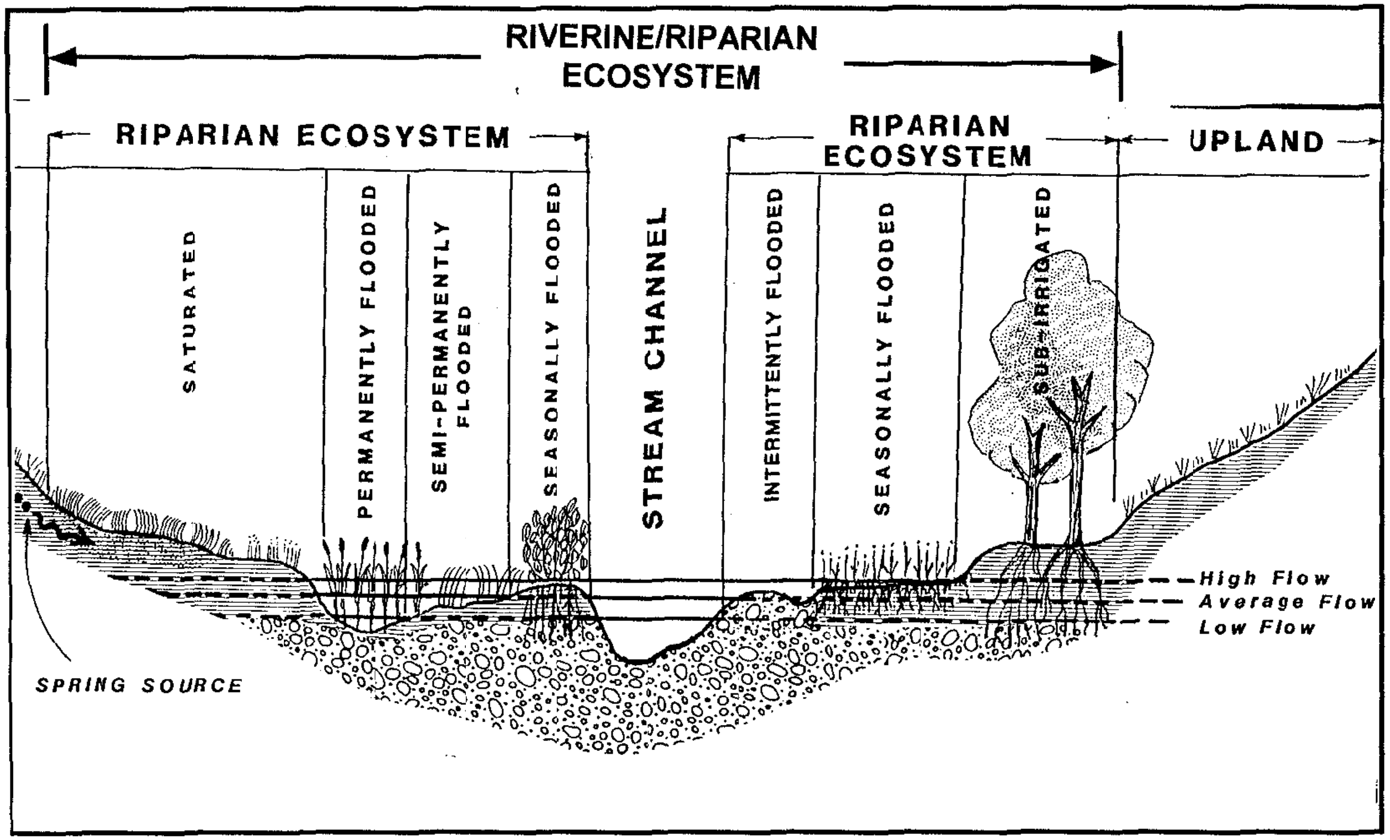

Figure 4. Water regimes.

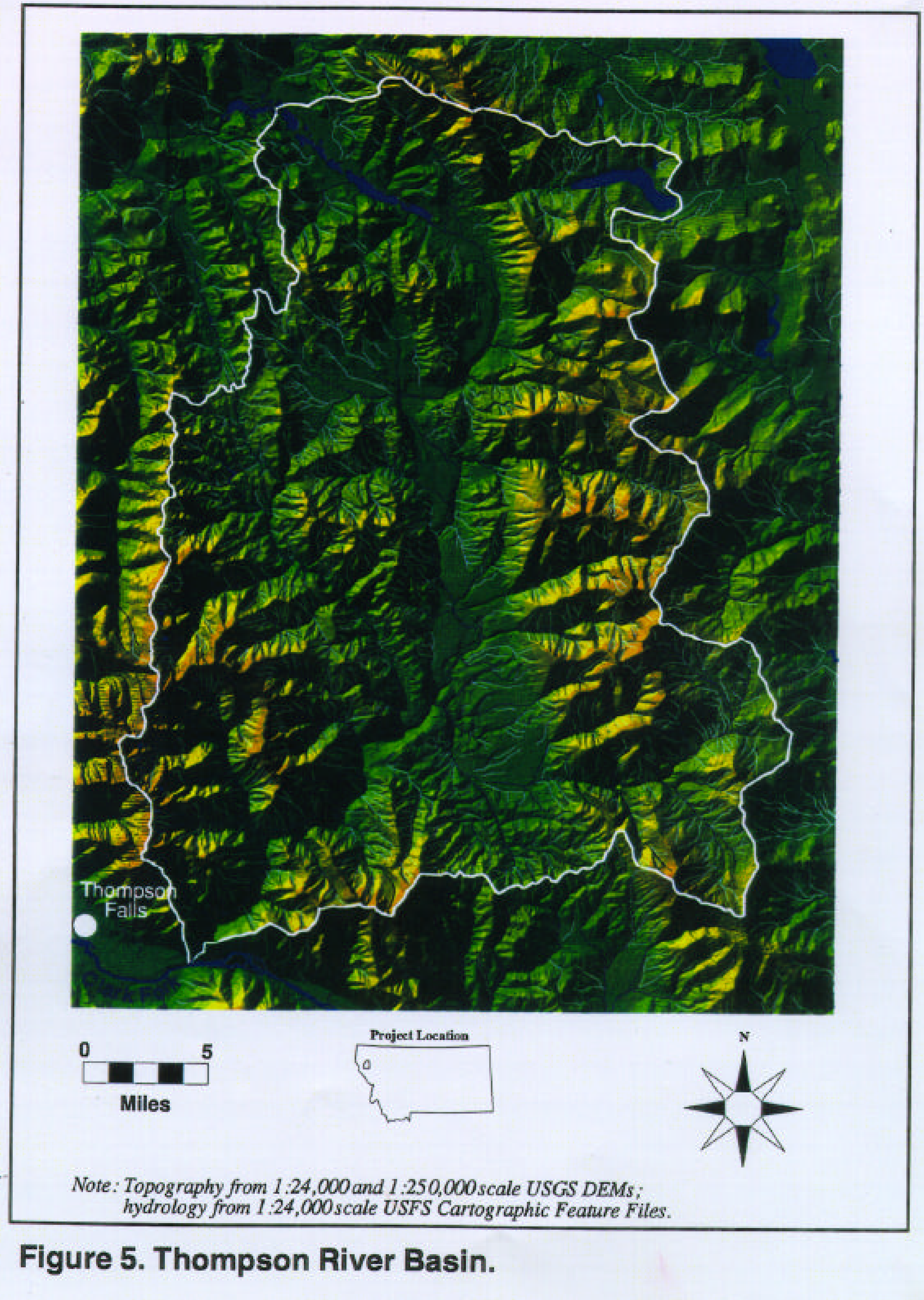

Figure 5. Thompson River Basin.

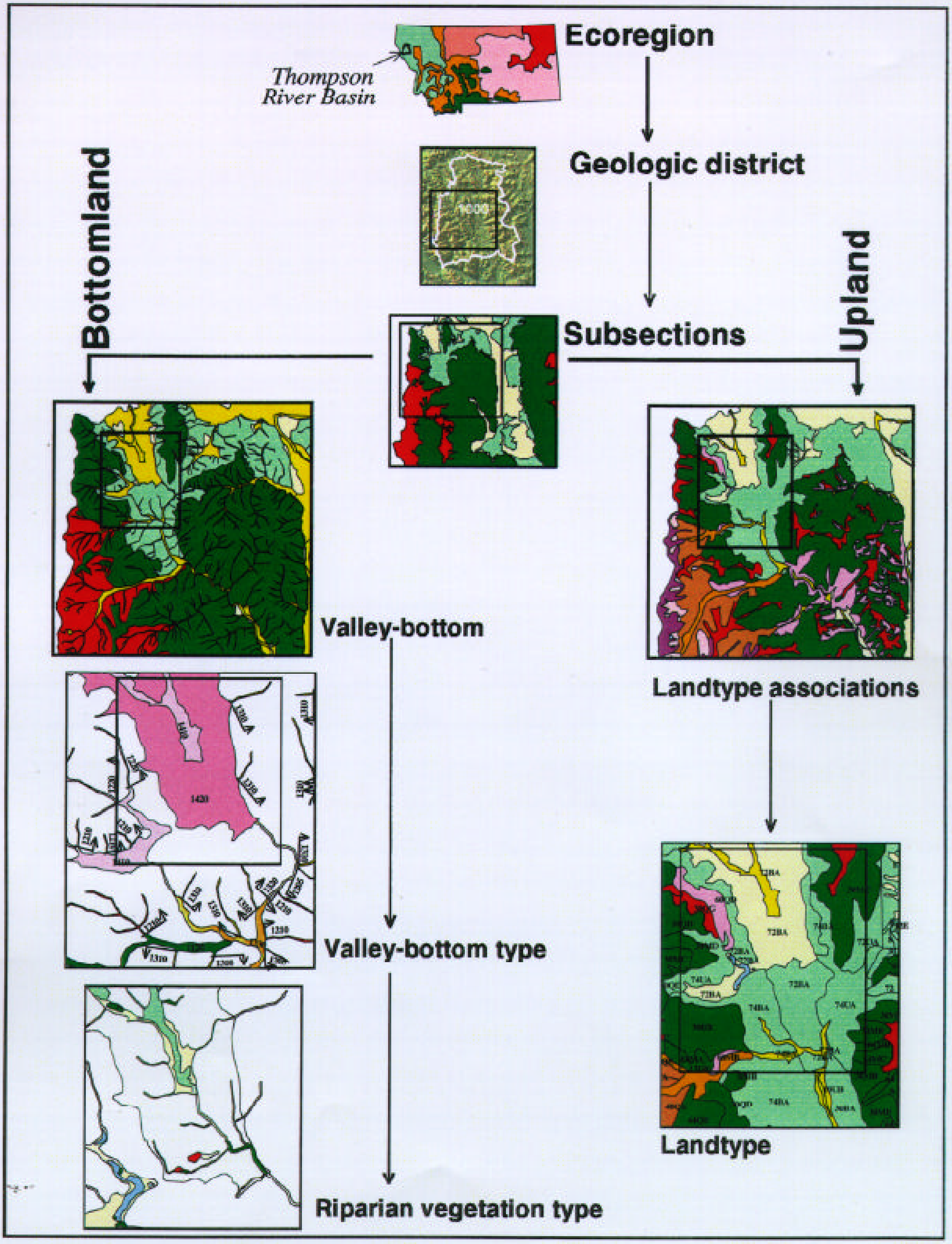

Figure 6. Classification hierarchy

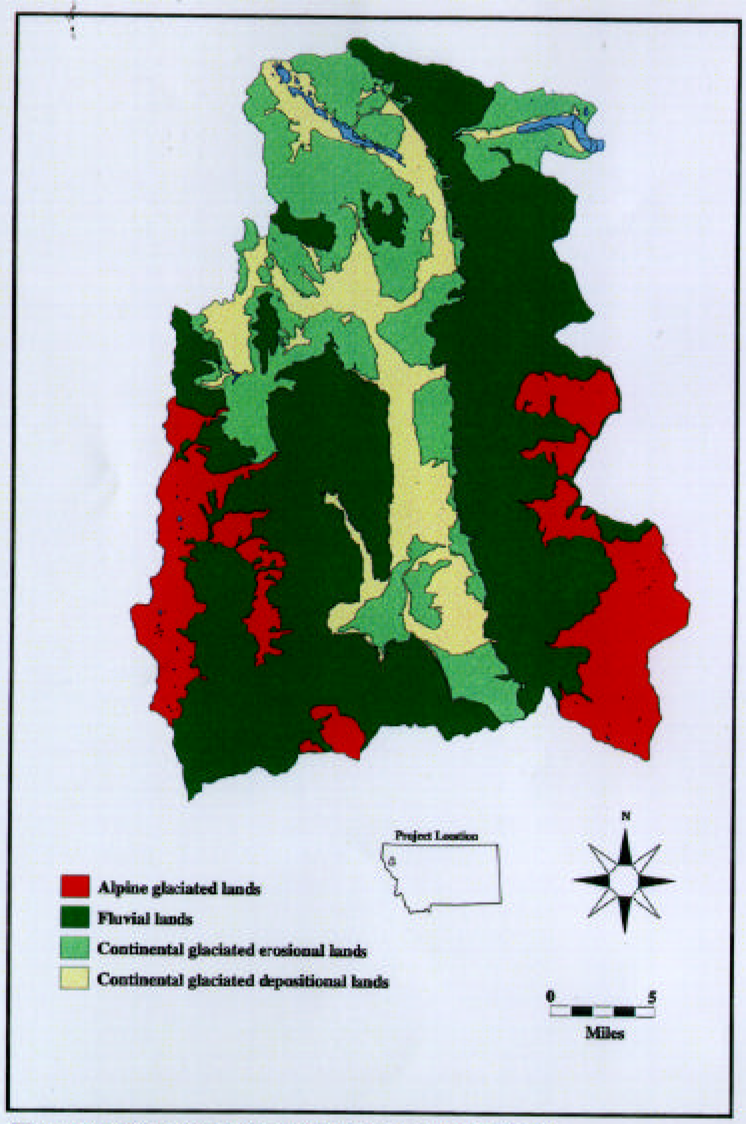

Figure 7. Subsections, Thompson River basin.

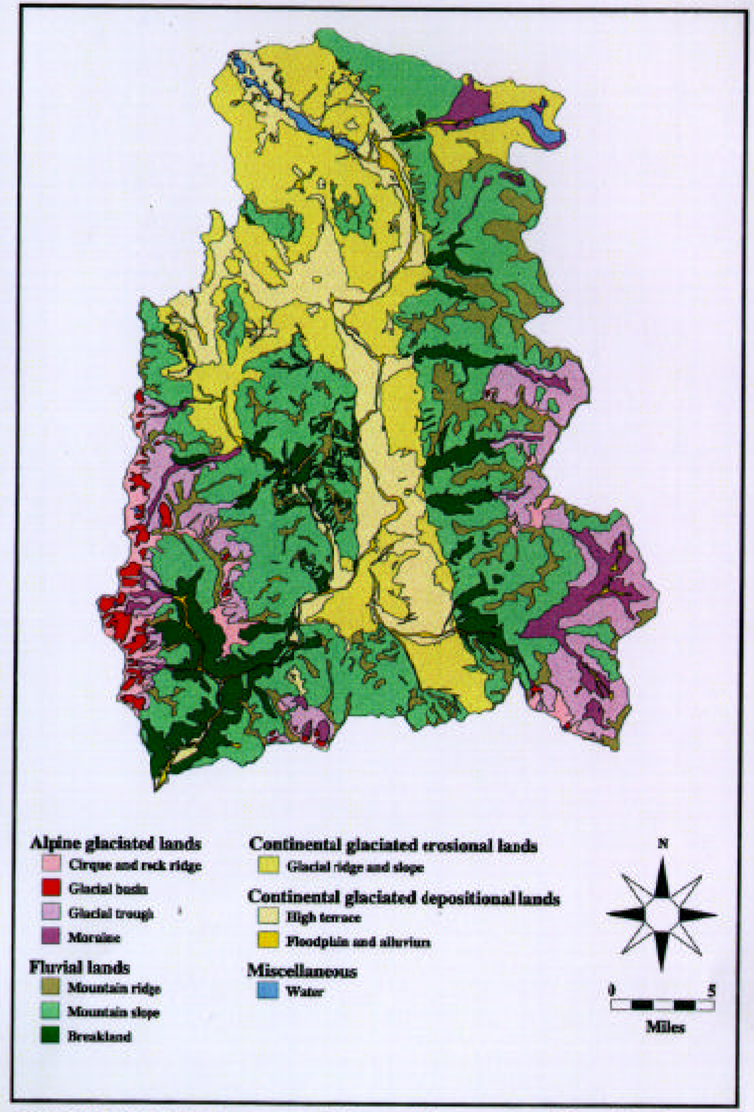

Figure 8. Landtype associations, Thompson River basin.

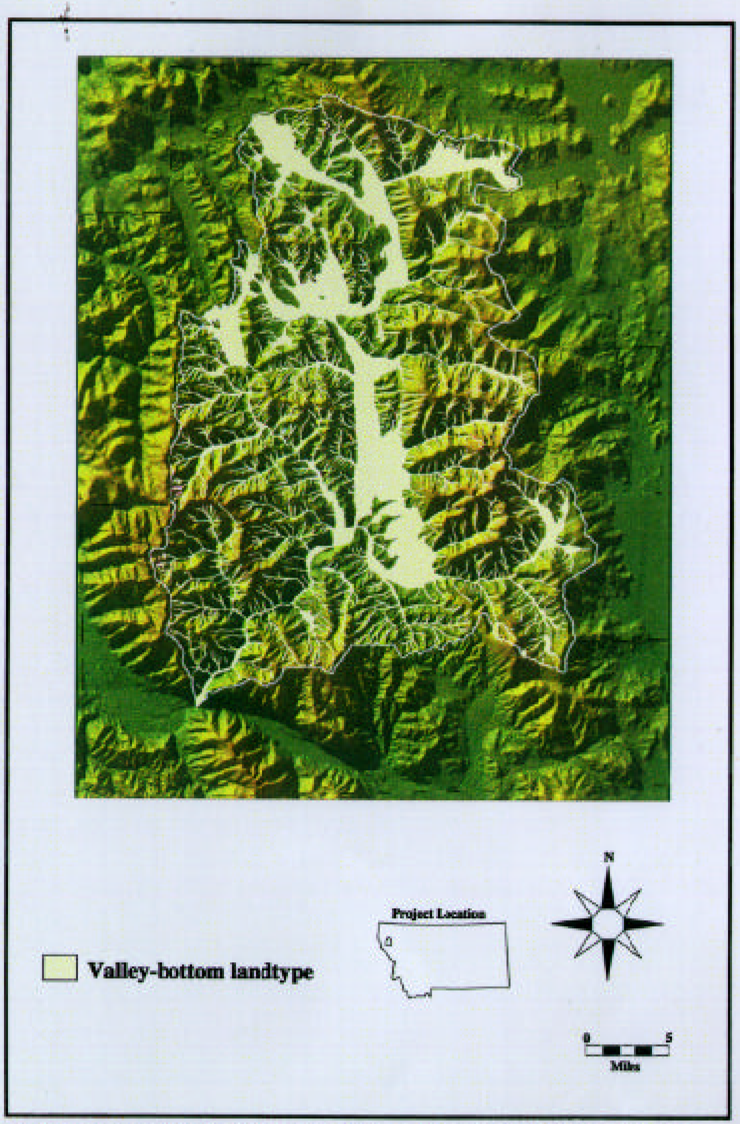

Figure 9. Valley-bottom landtype, Thompson River basin.

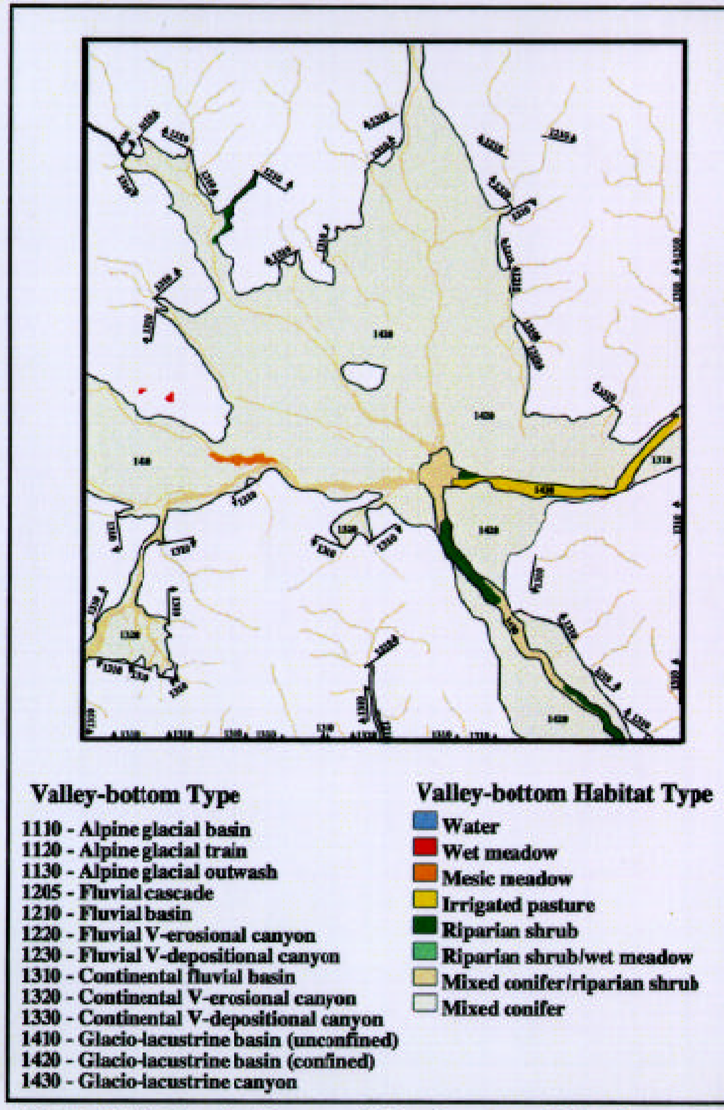

Figure 10. Valley-bottom and riparian vegetation types.

Note: Topography from 1:250,000 scale USGS DEMs; hydrology from 1:2,000,000 scale USGS DLGs.

Figure 11. Ecological classification study areas.